RESEARCH DEPARTMENT

Simultaneous long distance tropospheric propagation measurements at 560 Mc/s and 774 Mc/s over the North Sea

RESEARCH REPORT No. K-178

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THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

SIMULTANEOUS LONG DISTANCE TROPOSPHERIC PROPAGATION MEASUREMENTS AT 560 Mc/s AND 774 Mc/s OVER THE NORTH SEA

Research Report No. K-178
(1965/2)

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SUMMARY

Simultaneous field strength measurements on u.h.f. transmissions at 560 Mc/s and 774 Mc/s were carried out over the North Sea, on transmission paths ranging from 123 miles (198 km) to 591 miles (950 km). The results show that with the same meteorological conditions the long-term received field strengths tend to be higher, although not to a significant extent, for the 774 Mc/s transmission than for the 560 Mc/s transmission.

When meteorological conditions are favourable during anticyclonic weather, the signals received are, at times, very much in excess of the free-space value. These high signals are associated with horizontally stratified boundary layers at heights up to 500 metres resulting from subsidence in the lower atmosphere. Boundary layers at greater heights are thought to be partly responsible for the signals received at the greater distances during abnormal propagation conditions.

The field strength exceeded in each month for certain time-percentages, the types of signal received and the fading rate are also discussed.

1. INTRODUCTION

The sharing of v.h.f. and u.h.f. television channels by the United Kingdom and Continental countries is the inevitable consequence of the limited frequency spectrum allocated to broadcasting. Information was required on oversea propagation so that the distance separation between stations could be planned to limit the probability of mutual interference during periods of abnormal propagation.

During the past decade the BBC, with the co-operation of the Netherlands Postal and Telecommunications Services, have completed a series of long distance propagation measurements over the North Sea in the Broadcasting Bands II, III and IV.[1,2,3] The results of these measurements were used in conjunction with data from other administrations to derive the C.C.I.R. (Geneva 1963)[4] oversea field-strength/distance curves. As a continuation of the oversea tests, Band V measurements at 774 Mc/s were commenced in the latter part of 1961.

At no time in the past had the oversea experiments been made simultaneously at two frequencies, and while a comparison of the final curves of the previous tests in each of the bands gives some indication of the effect of frequency in long distance propagation over the sea, part of the differences which appear between them may be attributed to the different meteorological conditions that prevailed during each test period. It was decided, therefore, that during part of the 774·Mc/s experiment, measurements would be made simultaneously on a frequency of 560 Mc/s. The measurements commenced on the 13th October 1961 and terminated on the 30th June 1962.

The transmitting station was at Scheveningen in Holland and five BBC receiving stations were situated on the East Coast of the United Kingdom at distances ranging from 123 miles (198 km) to 591 miles (950 km).

2. TRANSMITTING AND RECEIVING SITES

2.1. Transmitting Site

BBC Research Department transmitters utilizing frequencies of 560 Mc/s and 774 Mc/s were installed and operated by the Netherlands Postal and Telecommunications Services at Scheveningen Radio Station. Each transmission was square-wave modulated at 1000 c/s to a depth of 100%, the modulation being cut for two seconds every minute for identification purposes at the receiving sites.

The 560 Mc/s transmitting aerial was a two-stack five-element Yagi with a reflector screen. Its intrinsic gain relative to a $\lambda/2$ dipole was 13 dB, and its half-power beamwidth ± 23°. The 774 Mc/s aerial was a corner reflector with an intrinsic gain of 13·5 dB, the half-power beamwidth being ± 24°. Each aerial was horizontally polarized and was mounted on a separate mast at a height of 155 feet (47 metres) above ground level. For all transmission paths the radio horizon was the sea. Further transmitting site details are given in Table 1.

The daily schedule of transmission was 0830 - 2300 hours, British Local Time.

TABLE 1

Transmitting Site Details

LOCATION	FREQUENCY	E.R.P. IN DIRECTION OF MAXIMUM RADIATION	DIRECTION OF MAXIMUM RADIATION	SITE HEIGHT ABOVE MEAN SEA LEVEL		LATITUDE	LONGITUDE
	Mc/s	kW	True Bearing	ft	m		
Scheveningen	560	1·95	320°	43	13·1	52°06'N	04°16'E
Scheveningen	774	0·95	320°	43	13·1	52°06'N	04°16'E

2.2. Receiving Sites

The receiving sites were at Happisburgh (Norfolk), Flamborough Head (Yorkshire), Newton-by-the-Sea (Northumberland), Bridge of Don (Aberdeen) and Lerwick (Shetland Islands). Fig. 1 shows the geographical distribution of the sites and Table 2 gives additional receiving site details.

TABLE 2

Receiving Site Details

LOCATION	DISTANCE FROM TRANS-MITTER		SITE HEIGHT ABOVE MEAN SEA LEVEL		AERIAL HEIGHT ABOVE GROUND LEVEL				TRUE BEARING OF SITE FROM TRANS-MITTER	LATITUDE	LONGITUDE
					560 Mc/s		774 Mc/s				
	ml	km	ft	m	ft	m	ft	m			
Happisburgh	123	198	50	15·2	32	9·8	28	8·5	295°	52°49'42"N	01°31'38"E
Flamborough Head	227	365	150	45·7	32	9·8	28	8·5	309°	54°07'39"N	00°05'40"W
Newton-by-the-Sea	338	543	70	21·3	32	9·8	28	8·5	317°	55°31'06"N	01°37'05"W
Bridge of Don	429	690	30	9·1	32	9·8	28	8·5	326°	57°10'40"N	02°05'00"W
Lerwick	591	950	300	91·5	32	9·8	28	8·5	342°	60°08'00"N	01°10'20"W

The u.h.f. receiver used for the measurements has been described in other Research Department Reports.[5,6] Its main features were high sensitivity and stability of calibration. The recording law was approximately logarithmic with a signal range of about 50 dB, but it was found that this range was insufficient during abnormal propagation conditions. Accordingly, a 30 dB attenuator, which came into circuit at high levels of signal, was introduced between the signal- and intermediate-frequency units. It was operated by a 1 milliampere relay in series with the recording milliammeter, whose full scale deflection was also 1 milliampere. Thus, when the meter deflection approached its maximum, the relay operated and attenuated the signal output, bringing the metering current within recording range. The circuit remained in this condition for about three hours, and the attenuator was then switched out. If the signal had in the meantime dropped in level, recording continued normally; if, however, the signal level was still high, the attenuator was again brought into circuit.

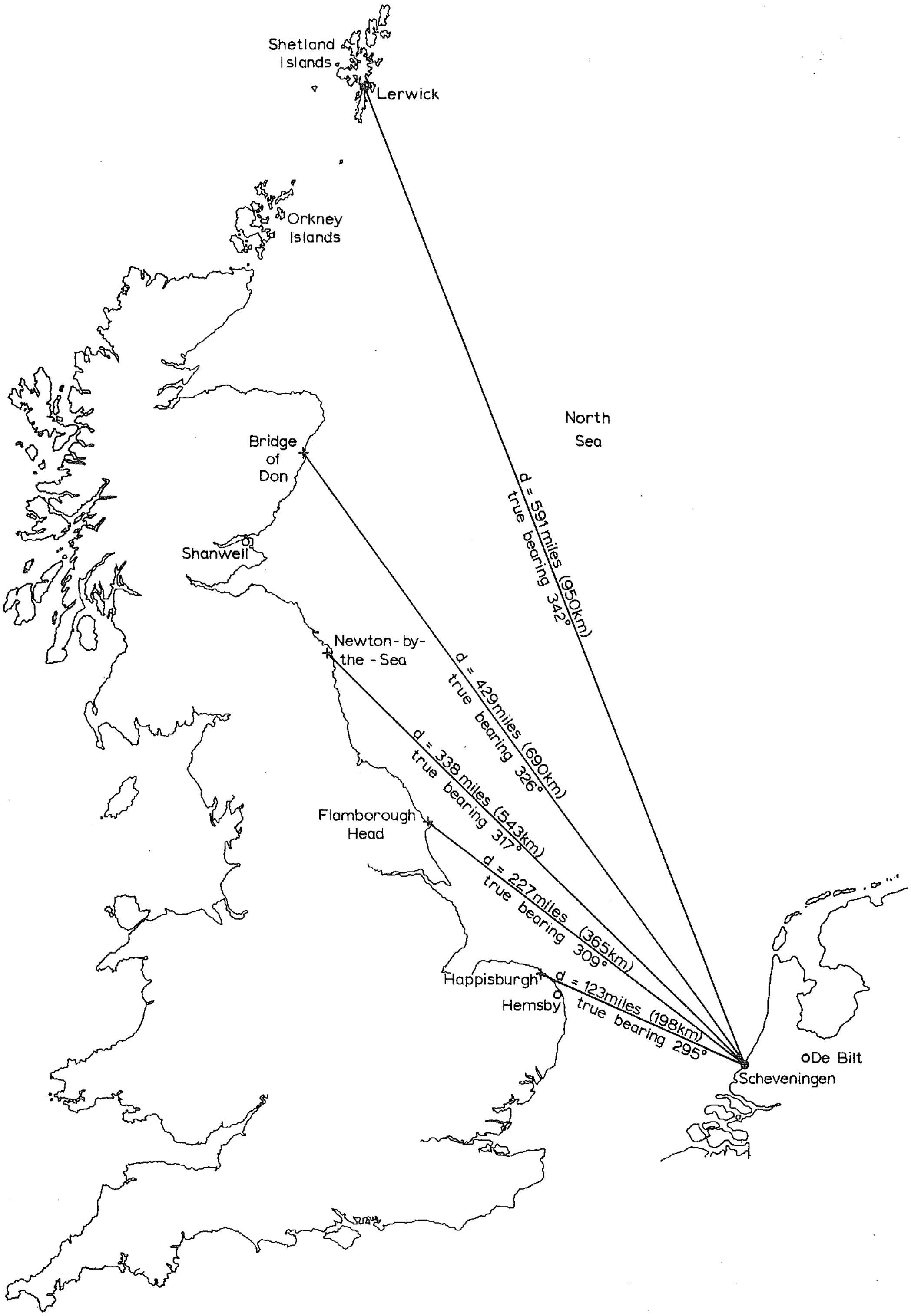

Shetland Islands
Lerwick
Orkney Islands
North Sea
Bridge of Don
Shanwell
Newton-by-the-Sea
Flamborough Head
Happisburgh
Hemsby
De Bilt
Scheveningen
d = 591miles (950km) true bearing 342°
d = 429miles (690km) true bearing 326°
d = 338 miles (543km) true bearing 317°
d = 227miles (365km) true bearing 309°
d = 123miles (198km) true bearing 295°

Fig. 1 - Geographical Distribution of Sites

● Transmitting Site
+ Receiving Sites
o Weather Stations

The 560 Mc/s and 774 Mc/s receiving aerials were of the Yagi two-stack ten-element type and each had an intrinsic gain in the region of 12 dB, relative to a $\lambda/2$ dipole and a half-power beamwidth of approximately ± 18°.

At the most distant sites, the receiver sensitivity, the aerial and its associated feeder were checked by a sweep-frequency calibration oscillator[7] at the close of each day's recording. The oscillator signal, radiating from a test dipole situated in the vicinity of the receiving aerial, swept through a frequency band of several megacycles centred on the frequency to which the receiver was tuned. The recorder trace is thus a check on the overall pass-band and the sensitivity of the receiver. The 560 Mc/s and 774 Mc/s systems had separate oscillators and test dipoles. At the nearer sites where no automatic checks had been installed the receiving system parameters were checked during routine visits.

The recorder charts were run at a speed of 3 in. (7·6 cm) and 6 in. (15·2 cm) per hour depending upon the type of fading normally received at the site.

3. RESULTS

3.1. Analysis

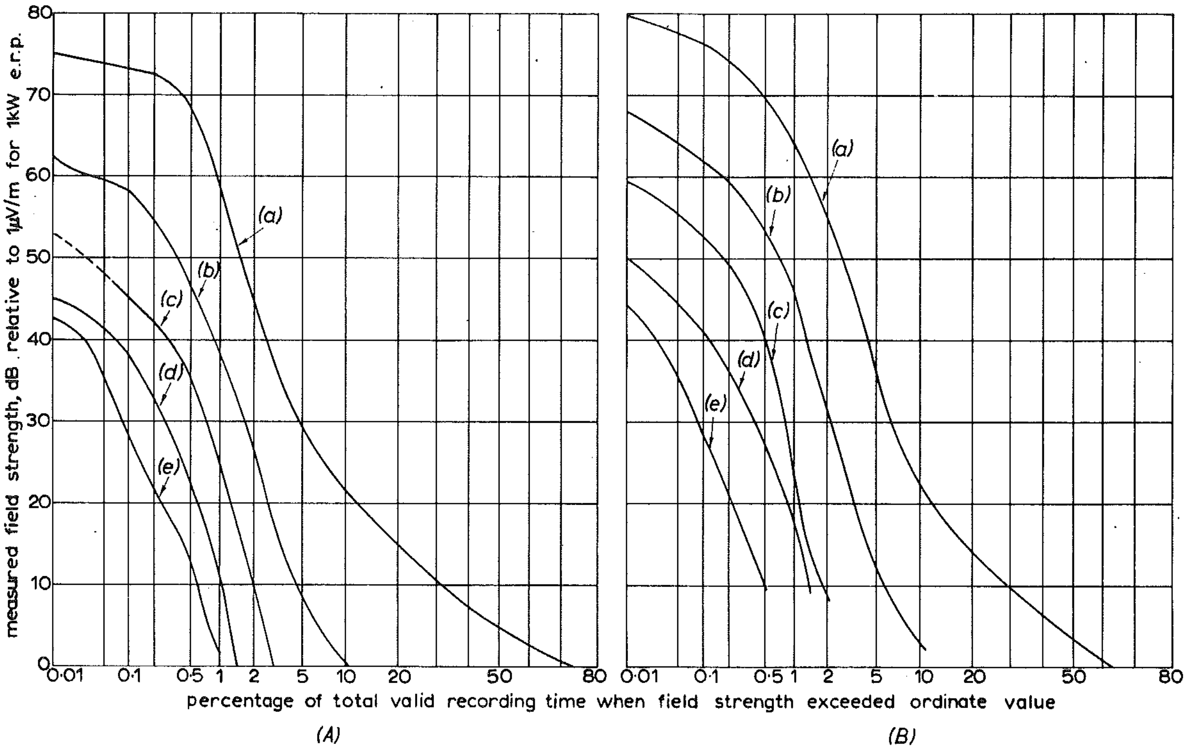
The field strength recording charts were analysed on a daily basis, grouped into months and finally the months' results were assembled to give the overall data for each transmission path.

The records of the measurements were analysed to determine the length of time during which signal levels exceeded various values of field strength. These time durations, expressed as percentages of the overall valid recording time, were then plotted against field strength in decibels relative to 1μV/m (dB(μV/m)) for an e.r.p. of 1 kW. The field strength exceeded for 0·1%, 1%, 10% and 50% of the overall time was plotted against each of the distances at which the recordings were made. A family of curves was then constructed to show the variation of field strength against distance.

3.2. Variation of Field Strength with Time

Figs. 2(A) and 2(B) give the results of the measurements made at each of the East Coast sites and are plotted as field strength exceeded against percentage of total time for the 560 Mc/s and 774 Mc/s transmissions. The Newton-by-the-Sea 560 Mc/s curve has been extrapolated to the 0·01% time value as no record of field strength above 47 dB was attained owing to a receiving equipment fault. The accompanying table for these curves gives the total hours recorded for each graph and the appropriate free-space field strength for each path.

Table 3, derived from Fig. 2, gives the field strengths exceeded for 0·1%, 1%, 10% and 50% of the total time. It will be observed that a few of the values listed in Table 3 have been obtained by extrapolation. These extrapolations were carried out to give further points for comparison purposes.



CURVES		RECEIVING SITE	DISTANCE		TOTAL HOURS RECORDED		FREE SPACE FIELD FOR 1 kW e.r.p.
Fig.2(A) 560 Mc/s	Fig.2(B) 774 Mc/s		ml.	km.	560 Mc/s	774 Mc/s	(dB)
(a)	(a)	Happisburgh	123	198	3513	3683	61•0
(b)	(b)	Flamborough Head	227	365	3708	3685	55•6
(c)	(c)	Newton-by-the-Sea	338	543	3637	3472	52•2
(d)	(d)	Bridge of Don	429	690	3685	3688	50•2
(e)	(e)	Lerwick	591	950	3630	3714	47•3

Fig. 2 - Variation of Field Strength with Time

(A) 560 Mc/s Measurements
(B) 774 Mc/s Measurements

The ratio of the field strengths of the signals at the two frequencies and at each site is listed in Table 4 where it will be seen that all but one of the ratios for the 0·1%, 1% and 10% values show the 774 Mc/s signal to be higher. For 50% of the time at Happisburgh and Flamborough Head, however, the 774 Mc/s signal was the lower by a small amount. These ratios are consistent with assumptions that the 50% field strengths are predominantly due to scattering in turbulent conditions whereas the modes of propagation for the smaller time-percentages are refraction or specular reflection.

TABLE 3

Scheveningen Results - 560 Mc/s and 774 Mc/s

CURVES		RECEIVING SITE	DISTANCE	FIELD STRENGTH, dB(μV/m) FOR 1 kW E.R.P.							
Fig.2(A)	Fig.2(B)			560 Mc/s				774 Mc/s			
560 Mc/s	774 Mc/s		km	0·1%	1%	10%	50%	0·1%	1%	10%	50%
(a)	(a)	Happisburgh	198	73·0	59·0	21·5	5·0	76·5	64·0	22·5	3·5
(b)	(b)	Flamborough Head	365	58·5	38·5	0·5	-17·0*	62·0	46·0	3·0	-18·0*
(c)	(c)	Newton-by-the-Sea	543	45·0	24·5	-18·0*	NL	52·5	24·0	-16·0*	NL
(d)	(d)	Bridge of Don	690	38·0	11·5	NL	NL	41·0	18·0	NL	NL
(e)	(e)	Lerwick	950	28·5	2·0	NL	NL	28·5	2·0*	NL	NL

* Extrapolated Value

NL - Below Noise Level

TABLE 4

Ratio of 774 Mc/s to 560 Mc/s Field Strengths at each Receiving Site

RECEIVING SITE	DISTANCE	RATIO IN dB OF 774 Mc/s TO 560 Mc/s FIELD STRENGTHS			
	km	0·1%	1%	10%	50%
Happisburgh	198	3·5	5·0	1·0	-1·5
Flamborough Head	365	3·5	7·5	2·5	-1·0
Newton-by-the-Sea	543	7·5	-0·5	2·0	-
Bridge of Don	690	3·0	6·5	-	-
Lerwick	950	0	0	-	-

Table 5 gives the range of fading* between the 0·1% and 1%, 1% and 10% and 10% and 50% of the overall time for the signals at the two frequencies at each of the receiving sites. This table reveals that there is a trend for the range of fading between time-percentages to increase with distance. Another interesting feature is that the range of fading between the 1% and the 10% values is very much greater than for the 0·1% and 1%, and the 10% and 50% values. This shows that in a temperate climate such as is experienced in the United Kingdom, the transition to the abnormal type of propagation over long periods of time occurs between the 1% and 10% field strength values.

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* i.e. the difference in dB between the field strength exceeded for the smaller time-percentage and that exceeded for the larger time-percentage.

TABLE 5

Range of Fading between Various Time-Percentages

RECEIVING SITE	DISTANCE	RANGE OF FADING IN dB BETWEEN VARIOUS TIME-PERCENTAGES					
		0·1 - 1·0%		1·0 - 10%		10% - 50%	
	km	560 Mc/s	774 Mc/s	560 Mc/s	774 Mc/s	560 Mc/s	774 Mc/s
Happisburgh	198	14·0	12·5	37·5	41·5	21·0	19·0
Flamborough Head	365	20·0	16·0	38·0	43·0	17·5	21·0
Newton-by-the-Sea	543	20·5	28·5	42·5	40·0	-	-
Bridge of Don	690	26·5	23·0	-	-	-	-
Lerwick	950	26·5	26·5	-	-	-	-

3.3. Field Strength/Distance Curves

The field strengths listed in Table 3 are used to derive, by the method of least squares, the best-fit curves for the 0·1%, 1%, 10% and 50% time values. Separate best-fit lines are calculated for the 560 Mc/s, 774 Mc/s and the combined 560 Mc/s and 774 Mc/s measurements using an inverse power-law relationship. Field strength, E, is therefore assumed to vary with distance, d, in the form $E = k/d^m$ where k is a parameter related to the transmission path and the transmitter power, and m is the slope of the best-fit line. Values of m and 20 log k are given in Table 6 for the selected time-percentages.

TABLE 6

Slope of Field Strength/Distance Curves

TIME PERCENTAGE	560 Mc/s		774 Mc/s		COMBINED 560 Mc/s AND 774 Mc/s	
	m	20 log k	m	20 log k	m	20 log k
0·1	-3·311	226·2	-3·473	238·4	-3·392	232·3
1·0	-4·262	255·7	-4·592	277·1	-4·427	266·4
10	-4·461	227·2	-4·333	222·5	-4·397	224·8
50	-4·142	195·2	-4·047	189·4	-4·095	192·3

The field strengths from Table 3, and the inverse power-law best-fit lines for 560 Mc/s, 774 Mc/s and the combined 560 Mc/s and 774 Mc/s results are plotted in Fig. 3. The 0·1% and 1% best-fit lines for the separate 560 Mc/s and 774 Mc/s measurements show that there is a difference at the two frequencies of about 5 dB at 200 km, reducing to 2 dB at 1000 km, the 774 Mc/s line being the higher of the two.

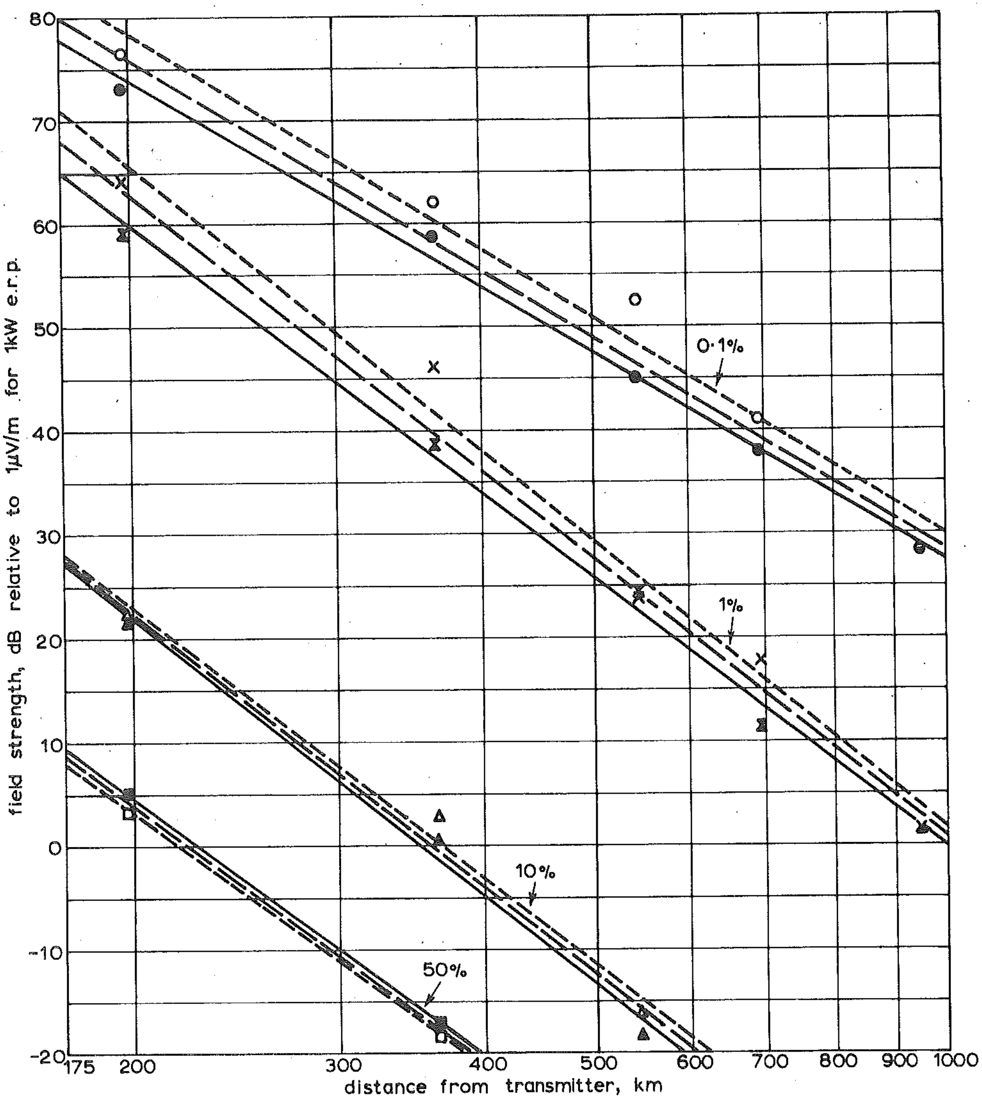


Fig. 3 - Variation of Field Strength with Distance

— · — · —	774 Mc/s
— — —	Combined 560 Mc/s and 774 Mc/s
———	560 Mc/s

●	0·1%	560 Mc/s	○	0·1%	774 Mc/s
⧗	1·0%	560 Mc/s	×	1·0%	774 Mc/s
▲	10%	560 Mc/s	△	10%	774 Mc/s
■	50%	560 Mc/s	□	50%	774 Mc/s

In the case of the 10% and 50% lines, the difference is approximately 1 to 2 dB for distances up to at least 600 km, both pairs of lines being nearly parallel; but whereas the 774 Mc/s line is higher than the 560 Mc/s for the 10% time, it is the lower for the 50% time curves. It should be borne in mind, however, that two of the four 50% field strength plots were extrapolated. The separate best-fit lines for each time-percentage show that, under the same meteorological conditions, there is little difference between the propagation of a signal in Band IV and one in Band V. For all practical purposes, therefore, the results of the simultaneous 560 Mc/s and 774 Mc/s transmissions are combined to give the appropriate best-fit lines, as shown in Fig. 3.

The combined 560 Mc/s and 774 Mc/s curves are plotted in Fig. 4, using a linear distance scale, and they are also compared with the oversea Bands IV and V C.C.I.R. curves. It will be noted that there is no 0·1% C.C.I.R. curve available for comparison. The C.C.I.R. 1% curve is lower than the combined 560 Mc/s and 774 Mc/s curve at distances less than 310 km, but higher at greater distances. The ratios

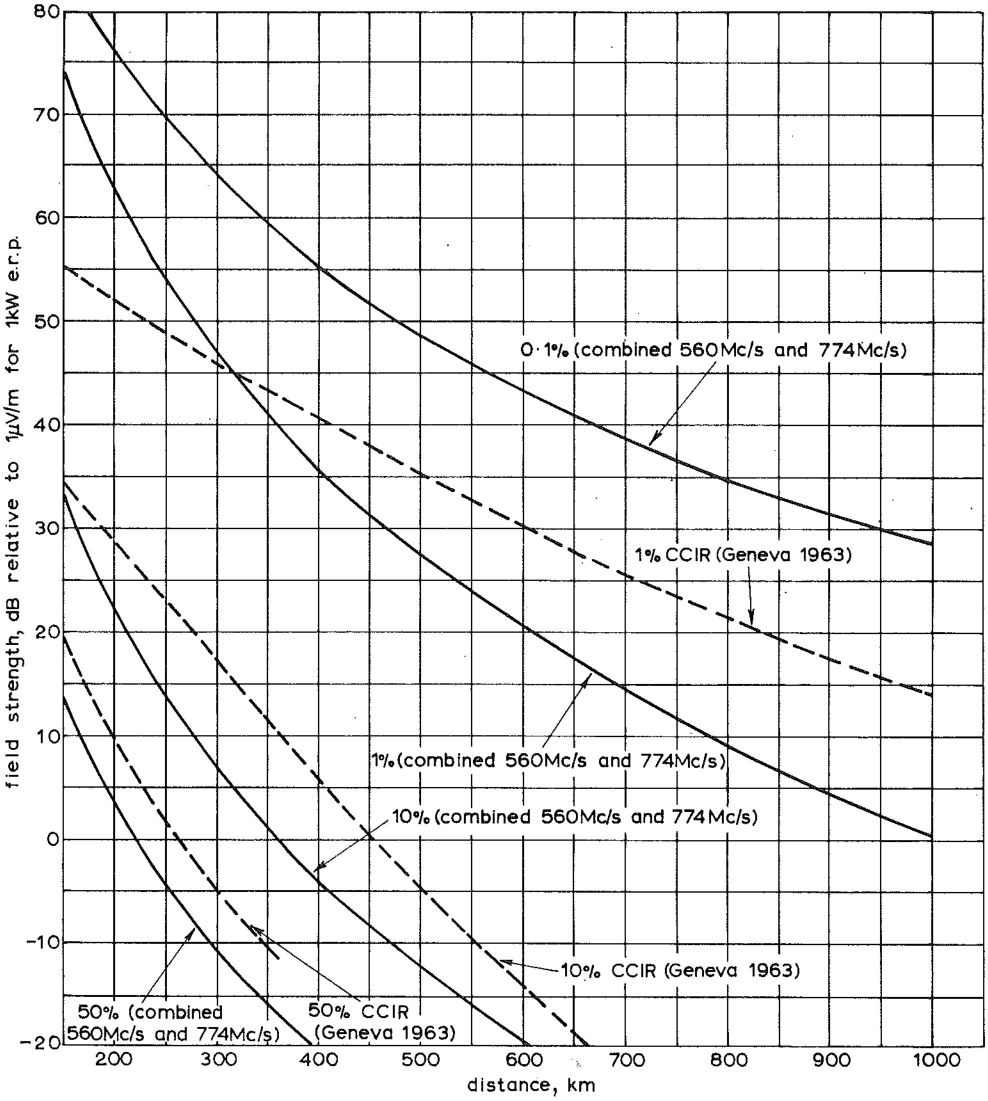


Fig. 4 - Comparison of 560 Mc/s and 774 Mc/s Oversea Field Strength/Distance Curves with C.C.I.R. (Geneva 1963) Curves

are -10 dB at 200 km and +13 dB at 1000 km, indicating a considerable difference in slope. The 10% and 50% curves of Fig. 4 are lower than the C.C.I.R. curves by about 5 to 10 dB between 200 and 600 km.

This comparison is given only for the sake of completeness, the main object of the work described in this report being to compare propagation on the two frequencies involved, rather than to measure the absolute value of field strength. In comparing the combined results with the C.C.I.R. curves it should be remembered that the measurements were made over a period of only 9 months, compared with a period of about 18 months for the C.C.I.R. curves, and the meteorological conditions may have been different. This is supported by the measured height slope of the 1% curve compared with the corresponding C.C.I.R. curve. Bearing this in mind, and also the variability of u.h.f. propagation, the differences indicated in Fig. 4 are not surprising.

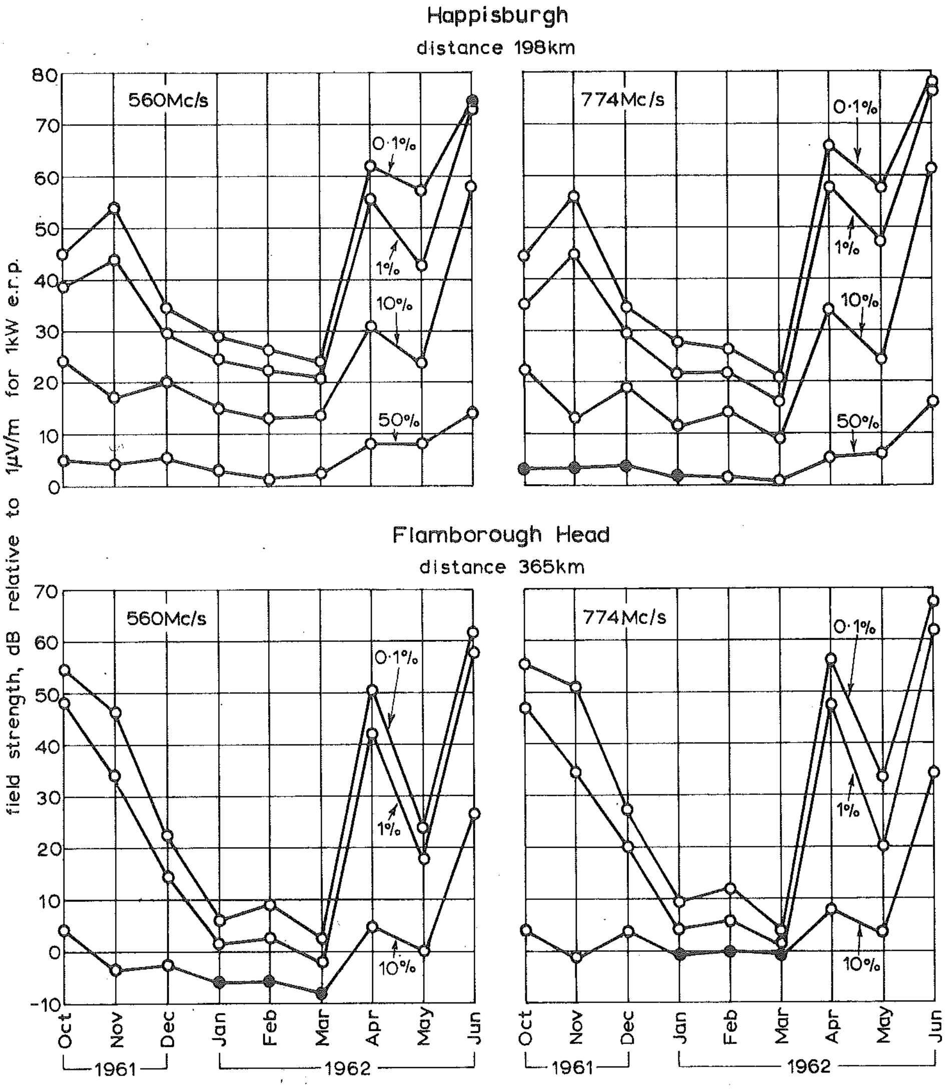


Fig. 5 - Field Strength Exceeded in each Month for Selected Time-Percentages

○ Measured Value
● Extrapolated Value

3.4. Monthly Field Strength Variations

The Happisburgh and Flamborough Head 560 Mc/s and 774 Mc/s field strengths exceeded in each month for selected time-percentages are shown in Fig. 5. The Flamborough Head 50% plots are not measurable because the signal is below the noise level of the receiver. There is not enough information to produce similar graphs for Newton-by-the-Sea, Bridge of Don and Lerwick, as signals at these sites are below the noise level of the receivers for the majority of the time.

Fig. 5 shows that for Happisburgh and Flamborough Head, the month-to-month variations in the field strengths exceeded at the different time-percentages increase with decreasing time-percentage. This also appears in Table 7 where the standard deviations of the monthly figures are given. Table 7 also shows that, for the majority of cases, the 774 Mc/s standard deviation is greater than the 560 Mc/s standard deviation. A comparison of the figures for the two sites indicates that the 0·1% and 1% standard deviations increase with distance at both frequencies, whereas the 10% values decrease. Information of a similar nature is given in Table 8 where the range of field strength exceeded in each month for each time-percentage is given for the nine-month period. The exceptionally high variations of field strength from one month to another for the 0·1%, 1% and 10% values emphasise the necessity for data on long distance tropospheric propagation to be obtained over extended periods of time.

TABLE 7

Standard Deviation of Field Strength Exceeded in each Month for Different Time-Percentages

RECEIVING SITE	PATH DISTANCE	STANDARD DEVIATION IN dB OF FIELD STRENGTHS EXCEEDED IN EACH MONTH FOR DIFFERENT TIME-PERCENTAGES							
		560 Mc/s				774 Mc/s			
	km	0·1%	1%	10%	50%	0·1%	1%	10%	50%
Happisburgh	198	17·8	17·2	14·1	3·8	19·9	19·6	16·3	4·7
Flamborough Head	365	22·8	22·1	10·5	-	23·4	21·7	11·2	-

TABLE 8

Range of Monthly Field Strengths
October 1961 - June 1962

RECEIVING SITE	PATH DISTANCE	RANGE OF MONTHLY FIELD STRENGTHS IN dB FOR STATED TIME-PERCENTAGES							
		560 Mc/s				774 Mc/s			
	km	0·1%	1%	10%	50%	0·1%	1%	10%	50%
Happisburgh	198	50·5	52·0	45·0	12·5	57·5	60·0	52·5	15·5
Flamborough Head	365	59·0	59·5	34·5	-	63·5	60·0	35·0	-

The variation of the 560 Mc/s and 774 Mc/s monthly field strengths for each transmission path follow the same pattern. On comparing different paths, however, the pattern may be dissimilar. The Happisburgh and Flamborough Head 0·1% and 1% plots for October and November 1961 show this effect. The Happisburgh 560 Mc/s and 774 Mc/s values are higher in November than in October whereas at Flamborough Head the October signals are higher. This is due to the position of the high pressure system relative to the transmission path. During October, when signals were abnormal, the centre of the high pressure system was situated over the North Sea, east of Flamborough Head and then it moved towards South Denmark, probably affecting the Flamborough Head path to a greater extent. In November, the high pressure systems were centred either over Central Europe or the Baltic region, extending over the North Sea and having a greater influence on the Happisburgh path. On the other hand, the 10% monthly field strength values at both sites follow the same trend, because for these values the signals approach normal propagation conditions. There are occasions, however, when the 10% value is influenced by a prolonged period of abnormal propagation and such a period occurred during the month of June 1962.

The graphs of Fig. 5 are reproduced on Fig. 6 in order to make a clearer comparison of the monthly field strength variations for the two transmissions at the same receiving site. Generally the Happisburgh 774 Mc/s field strengths exceed the 560 Mc/s value only during the months when abnormal propagation is prevalent. The Flamborough Head results, however, show that with two exceptions the 774 Mc/s field strengths are higher than the 560 Mc/s values during both abnormal and normal propagation conditions.

3.5. Types of Signals and Fading Rate

Signals received over long distances may be classified into three main groups, as follows:

Type I	Signals which are affected by comparatively little fading.
Type II	Signals which are affected by fading over periods of minutes.
Type III	Signals which are affected by rapid fading.

Fig. 7 shows selected samples of Happisburgh recorder charts illustrating the types of signals. Types I and II are normally associated with the high-level signals which occur during anticyclonic weather, although there are instances in which Type II is associated with low-level signals. Type III is associated with the low-level signals which are received during cyclonic weather.

An examination of the recorder charts for the period October 1961 to June 1962 revealed that, in general, the type of signal received at each site for both the 560 Mc/s and 774 Mc/s transmissions was similar. It was decided, therefore, that the Happisburgh 560 Mc/s recorder charts would be inspected in order to obtain the proportion of the total time in which the various types of signals were received. The charts for the more distant sites were not inspected, as in most instances the signals were received only during abnormal propagation conditions.

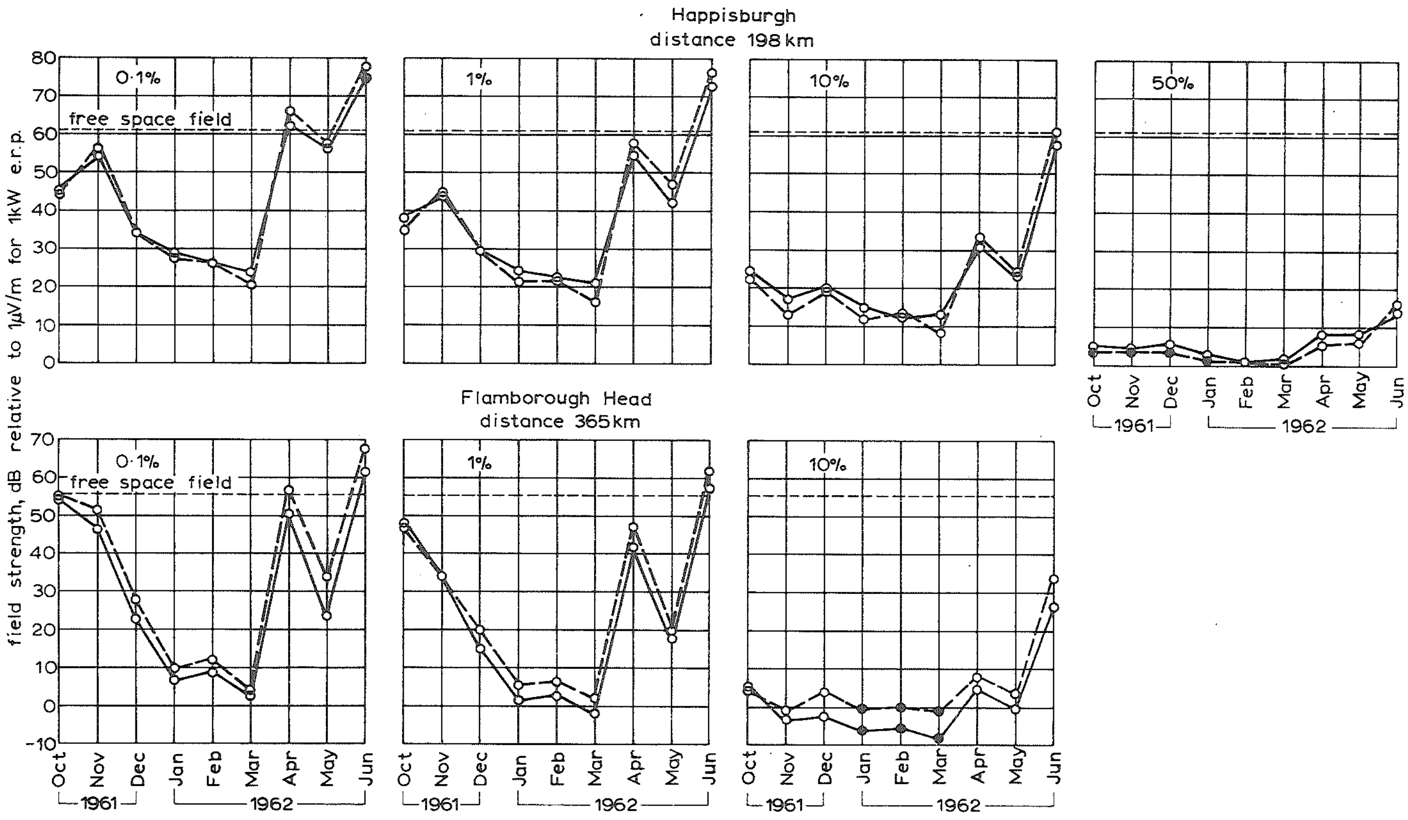


Fig. 6 - Comparison of 560 Mc/s and 774 Mc/s Field Strengths Exceeded in each Month

——— 560 Mc/s
— — — 774 Mc/s

○ Measured Value
● Extrapolated Value

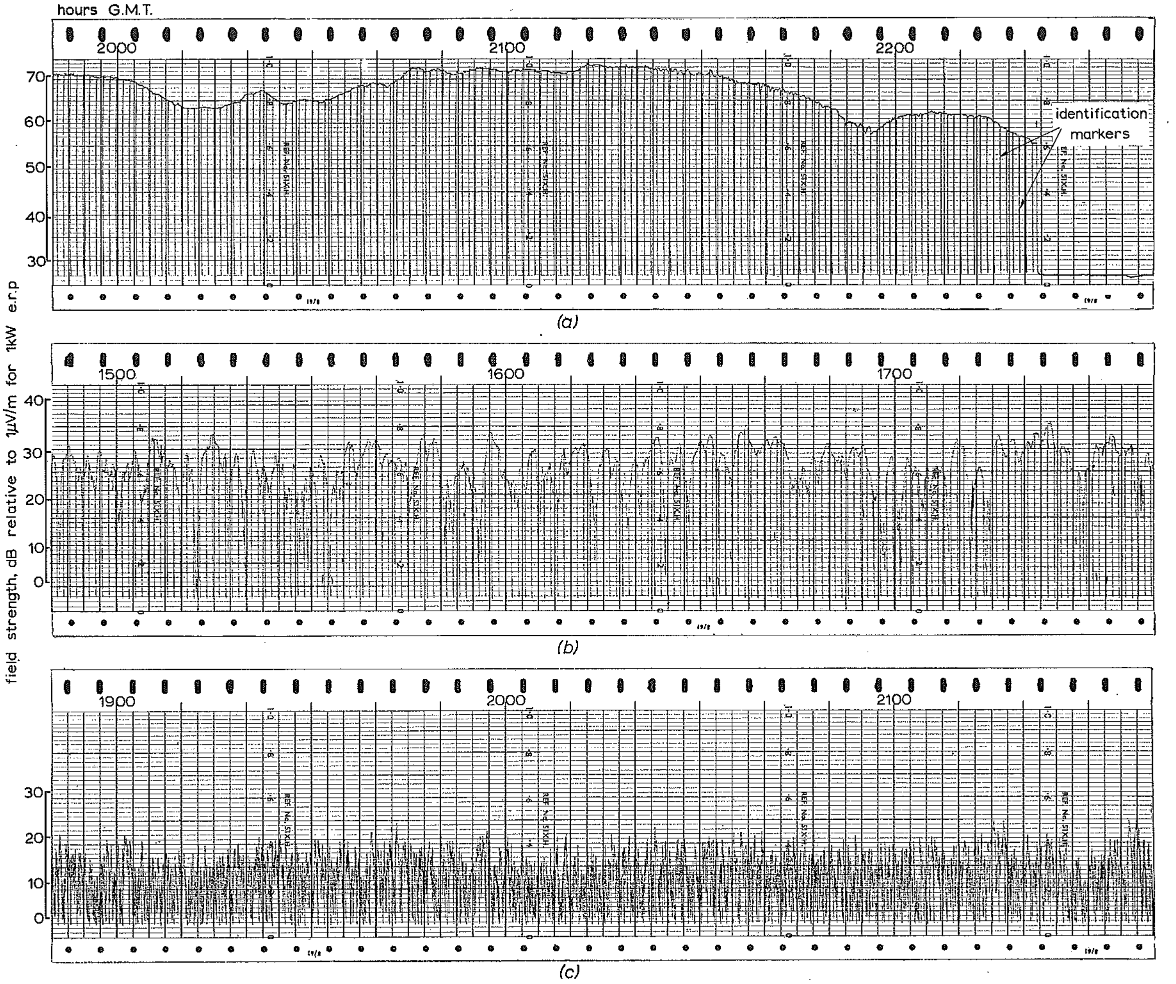


Fig. 7 - Types of Signals Received at Happisburgh

(a) Type I signal - 8th June 1962
(b) Type II signal - 23rd April 1962
(c) Type III signal - 18th March 1962

The type of signal and fading rate during the periods 1000 to 1030, 1400 to 1430 and 2100 to 2130 hours local time were noted. Table 9 gives the percentage of the time, for the appropriate half-hourly period, in which each type of signal was received. These half-hourly periods were then grouped to give an overall percentage as listed in the right-hand column of Table 9. The table reveals that there is very little difference in the percentage values between the 1000 to 1030 hours period and the 1400 to 1430 hours period. The percentages for the 2100 to 2130 hours period, however, show that Types I and II signals have higher values when compared with the other periods. As the Types I and II signals are generally associated with abnormal propagation, this indicates that these signals are more prevalent in the evening.

TABLE 9

Percentage of the Time during which the Various Types of Signals were Received at Happisburgh (560 Mc/s)

TYPE OF SIGNAL	PERIOD OF OBSERVATION			
	1000-1030 Hours	1400-1430 Hours	2100-2130 Hours	COMBINED PERIODS
I	0·8%	0·8%	1·6%	1·1%
II	5·0%	5·8%	6·7%	5·9%
III	94·2%	93·4%	91·7%	93·0%

The overall percentages for the various types show that, in general, the fast-fading, low-level type of signal occurs for 93% of the time, whereas the slow-fading, high-level type of signal occurs for the remaining period. These figures confirm the statement made in Section 3.2., that the transition to abnormal propagation occurred for the field strength values between 1% and 10% of the total time.

The fading rate in this report is defined as the number of times the signal crosses the median value in the positive direction per minute, the fading rate being obtained from the previously mentioned three half-hourly periods in each day. Table 10 gives the approximate fading rate for the different types of signal. A more detailed analysis could not be given, however, because of the relatively slow recorder chart speed used for the continuous measurements. Table 10 shows that the fading rate ratios of the three types of signal are approximately 1 : 10 : 100.

TABLE 10

Fading Rate for the Various Types of Signals - Happisburgh (560 Mc/s)

TYPE OF SIGNAL	FADING RATE
I	0·04
II	0·4
III	4·5

3.6. Abnormal Propagation

Fig. 5 shows that the highest signals received during this series of measurements were in June 1962, and the results for this month are used to illustrate abnormal propagation. These June values are listed in Table 11, where they are quoted relative to the free-space field strength. Table 11 shows that at Happisburgh, Flamborough Head and Newton-by-the-Sea signals approaching or in excess of the free-space field were received for the 0·1 and 1 time-percentages. At Bridge of Don and Lerwick the signals approach, but do not reach, the free-space field. It is also interesting to note that the Happisburgh 0·1 time-percentage signal for the 560 Mc/s transmission is 13·5 dB above the free-space value, while for the 774 Mc/s transmission it is 17·0 dB. An inspection of the June 1962 Happisburgh recorder charts showed that the peak signals for the 560 Mc/s and 774 Mc/s transmissions are 76 and 81 dB(μV/m), respectively. These signals are exceptionally high for a path length of 198 km being 15 and 20 dB above the free-space value. The peak signals at the other receiving sites also approach, and sometimes exceed the free-space value, the peak signals being approximately the same or slightly higher than the 0·01% field strength given for each site in Fig. 2.

TABLE 11

Received Field Strengths Relative to Free-Space Value - June 1962

RECEIVING SITE	FREE-SPACE FIELD dB (μV/m) FOR 1 kW E.R.P.	RECEIVED FIELD STRENGTH, dB RELATIVE TO FREE-SPACE VALUE FOR STATED TIME-PERCENTAGE							
		560 Mc/s				774 Mc/s			
		0·1%	1%	10%	50%	0·1%	1%	10%	50%
Happisburgh	61·0	13·5	12·0	-3·0	-47·0	17·0	15·5	0·5	-44·5
Flamborough Head	55·6	5·9	1·9	-29·1	-	11·9	6·4	-21·1	-
Newton-by-the-Sea	52·2	4·8	-9·3	-47·2	-	7·8	-0·2	-43·2	-
Bridge of Don	50·2	-3·2	-13·7	-	-	-0·2	-11·2	-	-
Lerwick	47·3	-3·3	-21·3	-	-	-2·8	-19·8	-	-

The abnormally high signals occurred from the 6th to the 9th June 1962 and the recorder charts for these days were analysed to obtain the variation of hourly median signals. The hourly median signals are plotted in Fig. 8. The 774 Mc/s signals at Bridge of Don could not be accurately obtained during these days because of an intermittent fault on the receiving aerial system.

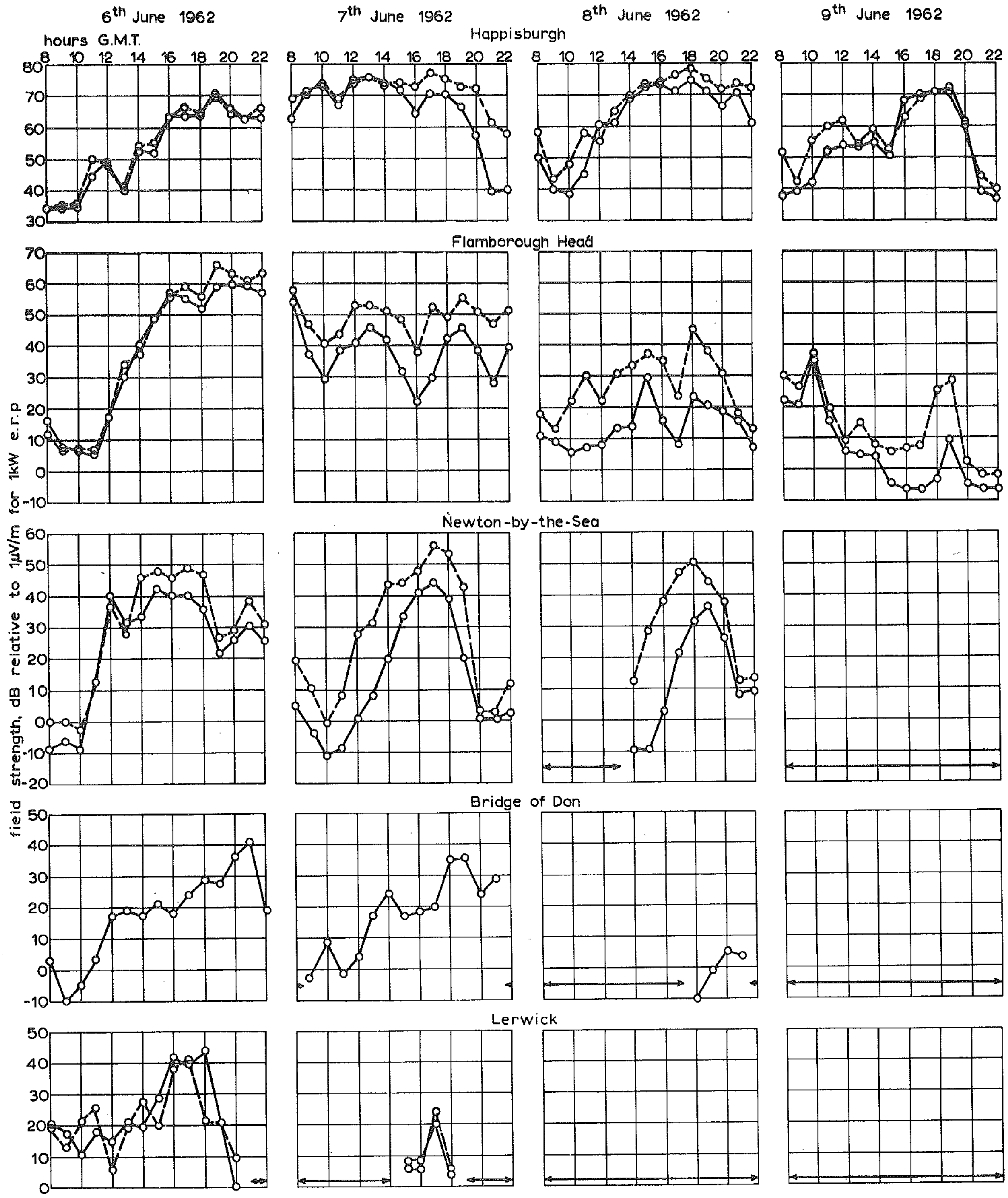


Fig. 8 - Variation of Hourly Median Signals 6th June to 9th June 1962

– – – – 774 Mc/s
—— 560 Mc/s

o Measured Value
←→ No Measurable Signal

Fig. 8 reveals that during the abnormal conditions prevalent at the time, the 774 Mc/s signal generally exceeded the 560 Mc/s signal. This effect is most noticeable at Flamborough Head and Newton-by-the-Sea. At Newton-by-the-Sea, for example, the hourly median signal on the afternoon of the 8th June shows that the 774 Mc/s signal reached a value as much as 38 dB above the 560 Mc/s signal. Another interesting feature, notably at Newton-by-the-Sea on the 7th and 8th June, is that the diurnal variation of signal reaches its peak at approximately 1800 hours. This effect is discussed in the next sub-section.

It is seen in Fig. 8 that exceptionally high signals were received on consecutive days close to peak television viewing periods, the high levels being maintained for several hours continuously each day. The severity of the interference that will occur between co-channel transmitters in such conditions will be appreciated when it is remembered that the field strengths quoted in Fig. 8 are for an e.r.p. of 1 kW whereas u.h.f. transmissions with an e.r.p. of up to 1000 kW are envisaged.

3.7. Meteorological Factors

3.7.1. General

It is well known that when the weather is anticyclonic, that is, at times of high barometric pressure, u.h.f. signals may be received at distances much greater than normal. The anomalous propagation occurs when meteorological conditions in the lower atmosphere produce a layer of dry, warm air over cooler, moist air. At the boundary between the dry and moist air a negative refractive-index gradient occurs. This gradient, being much greater than normal, causes the radio waves which are usually lost in space to be refracted back to the earth's surface. Should a large change in the refractive-index gradient extend down to the earth's surface, a 'ground based duct' may be formed and within this duct signals are propagated with little attenuation. Similarly, a large negative refractive-index variation with height in the lower atmosphere may act as an 'elevated duct'.

Anomalous propagation tends to be more widespread and continuous on oversea than on overland paths. The main reason is that the sea has no marked diurnal temperature variation and hence the air above it tends to remain cool and moist. The air from higher levels of the atmosphere in a high pressure area subsides and settles as a warm, dry layer over the cool, moist air. The junction of the two masses which is known as a 'subsidence boundary layer' or a 'temperature inversion' gives a sharp negative refractive-index gradient. Similar conditions occur over land, but in these instances, the air in the vicinity of the earth's surface is heated by the sun's rays, and there is not usually such a marked discontinuity in the refractive index as on oversea paths, at least during the day. In addition, the undulations of the terrain tend to break up any tendency to stratification. Another characteristic of oversea propagation is that air from neighbouring land masses may drift over the sea in late afternoon and early evening and accentuate any temperature inversion that already exists. This may partly account for the tendency of the diurnal variation of signal to be at its peak in the late afternoon and evening as shown in Fig. 8. The Newton-by-the-Sea signals on the 7th and 8th June are outstanding examples of this effect. On the other hand, the signals on the 6th and 7th June at Lerwick were also at a maximum in the late afternoon even though the land mass of the Shetland Islands is not extensive.

3.7.2. Potential Refractive Index (K)

The refractive index, n, of the troposphere varies with temperature, humidity and pressure. The refractive index is often given in terms of the co-index, N, where

$$N = (n-1).10^6$$

$$= \frac{77 \cdot 6}{T} (P + \frac{4810e}{T})$$

where T is the absolute temperature (°Kelvin)

P is the atmospheric pressure in millibars

e is the water vapour pressure in millibars.

There is a better parameter than the co-index, N, for representing pictorially the structure of the atmosphere. The normal changes of N with height tend to obscure phenomena which give rise to abnormal propagation. A parameter which removes altitude dependence from the expression for refractive index is 'Potential Refractive Index'.[8,9] This is denoted by K. The potential refractive index is defined as the value which the normal refractive index of a sample of air would acquire if this sample were taken adiabatically to a pressure of 1000 mb.

In order to derive K, the variation of temperature, humidity and pressure is used in conjunction with a meteorological temperature-entropy chart known as a 'tephigram'.[8] The Daily Aerological Records issued by the Meteorological Office list the temperatures, humidities and pressures from their daily measurements. This information is obtained from the 'radiosonde' ascents which are carried out twice daily at the main weather stations. As the ascents are primarily intended to assist meteorologists in weather forecasting, the fine structure of the atmosphere is generally not measured. To investigate the reception of high signals from Scheveningen the atmospheric region of interest is that over the North Sea. Unfortunately there are no weather ships in the North Sea and consequently there is no alternative but to use the data from the nearest weather station situated on the coastal areas. The records chosen for the investigation are those taken at Lerwick (Shetland Islands), Shanwell (Fifeshire), and Hemsby (Norfolk) in the United Kingdom, and at De Bilt in the Netherlands. The geographical position of these stations is shown in Fig. 1. It will be observed that they do not all lie on the same straight line.

3.7.3. Examples of Effect of Meteorological Factors on Propagation

The period 6th to 9th June 1962 already referred to in Fig. 8 is used to illustrate potential refractive-index cross-sections. These are shown in Fig. 9 (a) to (h). The K cross-sections are related to the appropriate Daily Weather Map (also issued by the Meteorological Office) by the alphabetical codes used to identify the 'pressure systems' and 'fronts'.

Fig. 9(a) shows the K cross-section for 0000 hours on the 6th June 1962. In this instance only Lerwick, Shanwell and Hemsby records were available as there was no radiosonde ascent at De Bilt. The steep refractive-index gradients occur where the K contours are closest to each other, that is, between 200 and 500 metres in this figure. This region is clearly a subsidence boundary. The subsidence boundary layer extends from Lerwick to Hemsby and is more intense at Shanwell.

Fig. 9(b) gives the 1200 hour cross-section for the same day. This shows that the subsidence results in two layers, one at heights between 50 and 350 metres and the other between 800 and 1150 metres. The two layers overlap in the region of Shanwell. Signals, (as shown in Fig. 8), were received at all the East Coast sites at 1200 hours on the 6th June, although they were not exceptionally high for the less distant paths.

The K cross-section in Fig. 9(c) shows that the boundary layer which previously existed at the 950 metre level has disappeared. The lower boundary layer now extends from Lerwick to De Bilt varying between 100 and 500 metres. This boundary layer is now more intense and no doubt accounts for the exceptionally high signals which were received towards the late evening of the 6th June.

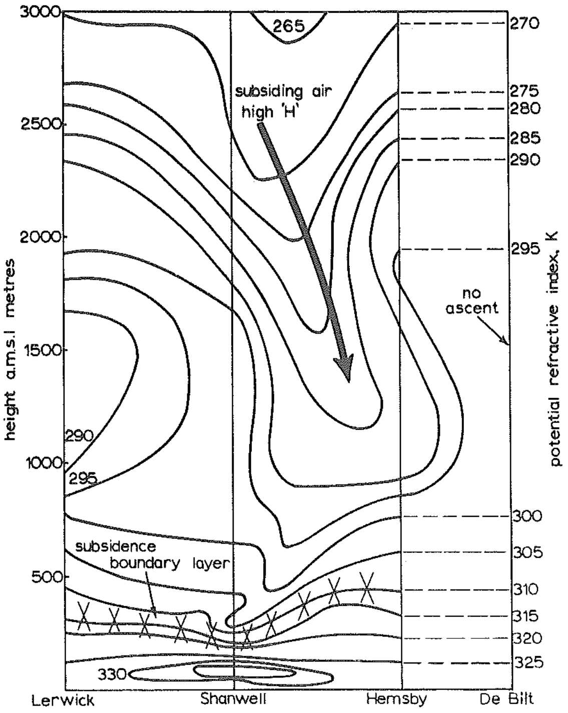
An inconsistency, however, occurs at 1200 hours on the 7th June as Fig. 9(d) reveals. At this time, very high signals were received at Happisburgh and Flamborough Head although no subsidence boundary layer is apparent in the region of Hemsby and De Bilt. It would appear, therefore, that no boundary layer existed over Hemsby and De Bilt although it may be assumed, with little doubt, that one existed over the North Sea. The layer existing in the region of Lerwick and Shanwell at an approximate height of 1350 metres was probably partially responsible for the signal received at Bridge of Don.

The daily weather map for 0000 hours on the 8th June shows that the air around Lerwick is influenced by front 'S'. This is noted in Fig. 9(e) which shows the K cross-section for the same time. The distribution of the contours at Lerwick indicates that the air is well mixed, and this probably accounts for the fact that no signals were received at Bridge of Don and Lerwick at 2200 hours on the 7th June.

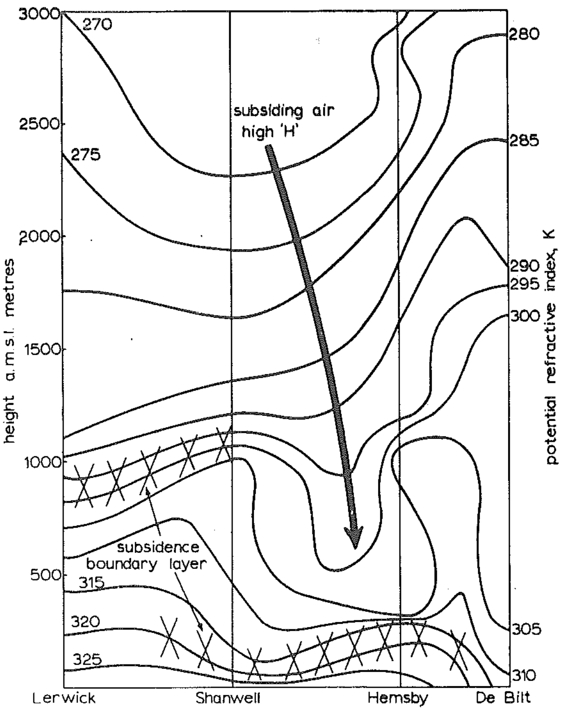
The cross-section of Fig. 9(f) for 1200 hours on the 8th June shows that the ascending moist air from front 'S' becomes more predominant in the area between Lerwick and Shanwell. There is a weak subsidence layer up to a height of 150 metres between Shanwell and Hemsby but this does not extend over De Bilt. Despite this, reasonably high signals were received at Happisburgh and Flamborough Head at this time.

Fig. 9(g) shows the subsiding air from High 'H' once again forming a high elevated layer. The layer height in this instance varied from 1200 to 1700 metres between Lerwick and Hemsby. Between Hemsby and De Bilt a lower layer also extends up to a height of 200 metres. It will be noted (Fig. 8) that at Happisburgh in the late evening of the 8th June, signals well above the free-space value were received. Signals were also received at this time at Flamborough Head and Newton-by-the-Sea although these were not particularly high.

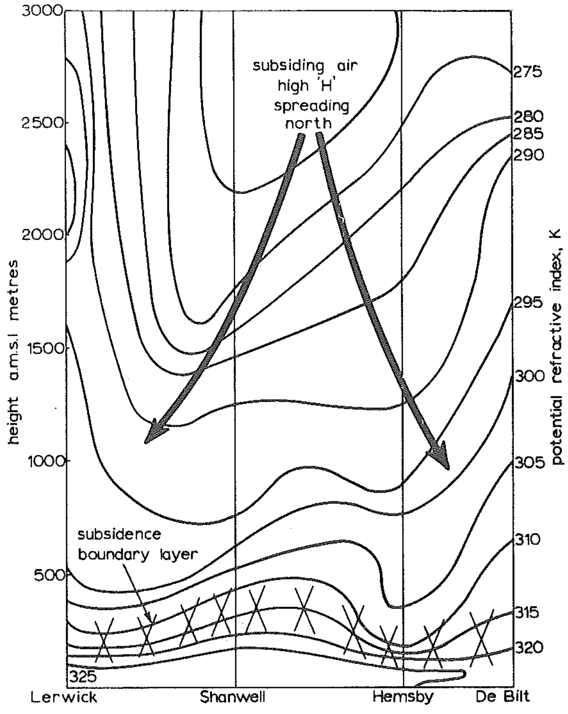
No well-defined inversion layers appear in Fig. 9(h). Despite this, the signals at Happisburgh were high. As in the example of Fig. 9(d) it may be conjectured that a boundary layer existed over the North Sea between Happisburgh and Scheveningen which was not apparent in the radiosonde measurements at Hemsby and De Bilt. It is interesting to note that the Happisburgh signals had increased in level still more by the late afternoon before dropping.



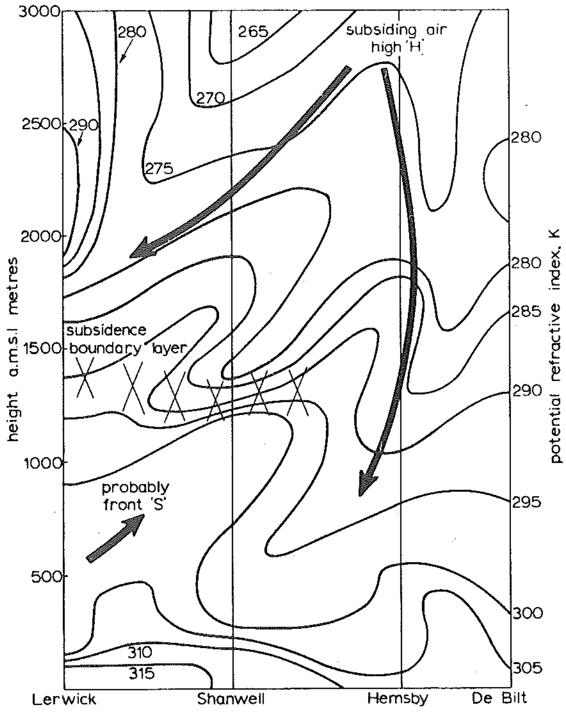
(a) 0000 Hours 6th June 1962



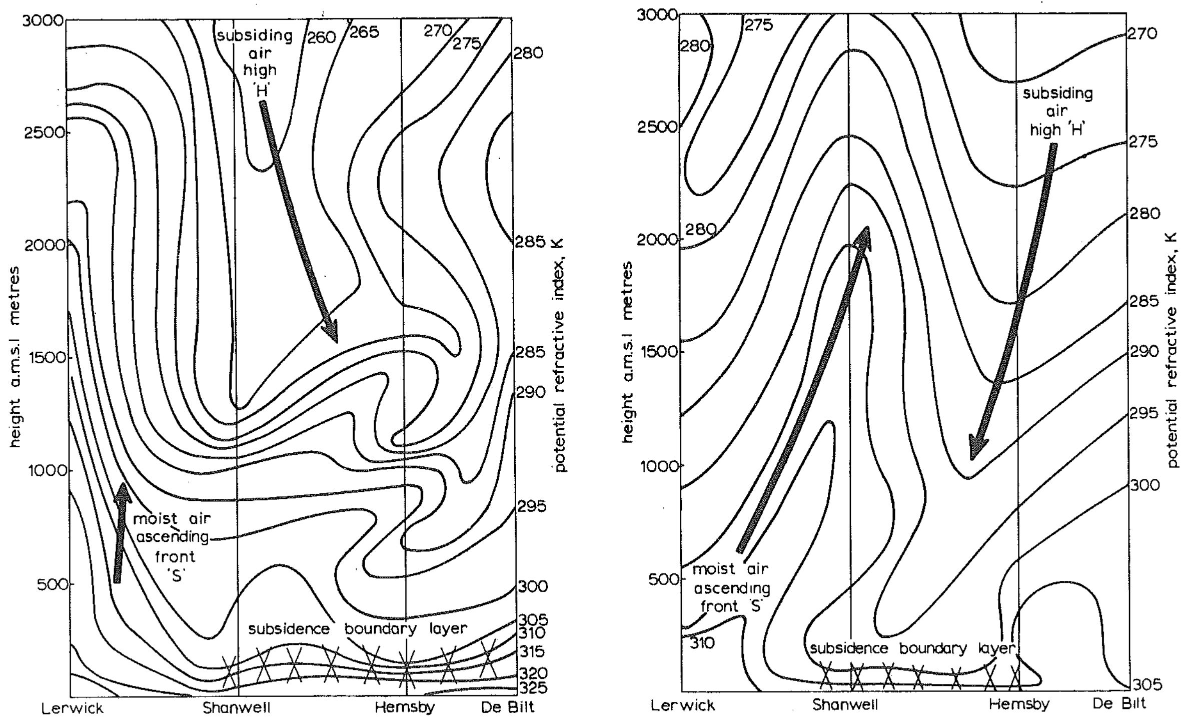
(b) 1200 Hours 6th June 1962



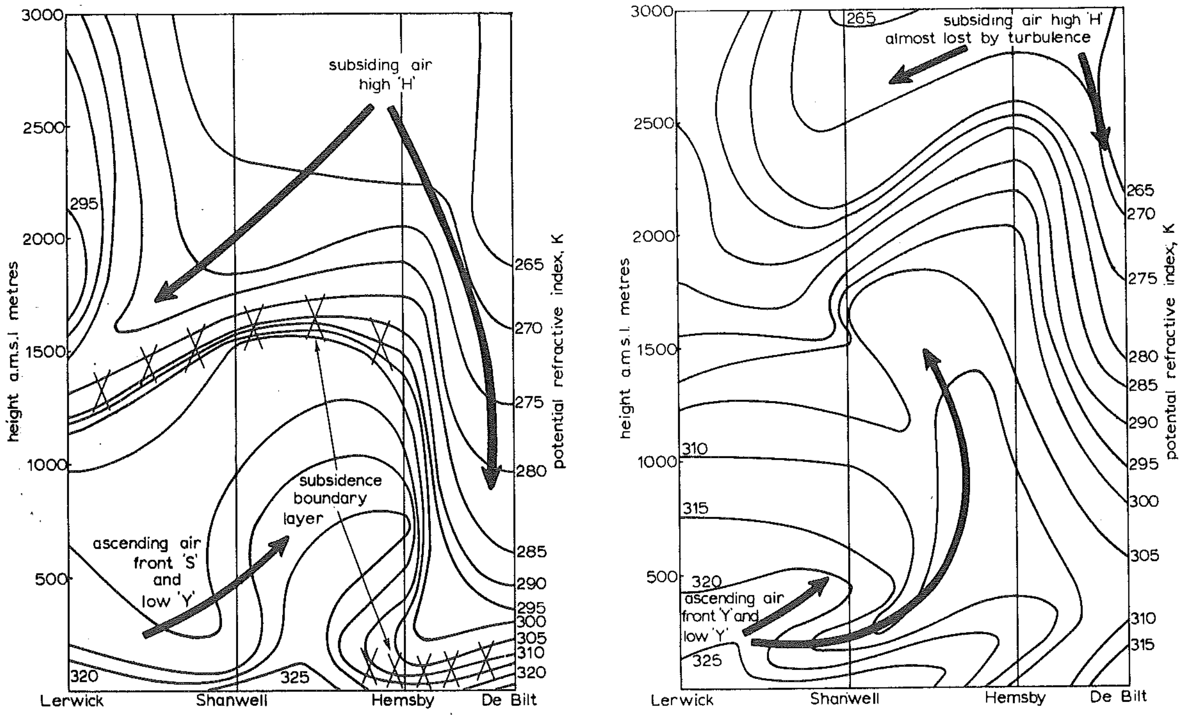
(c) 0000 Hours 7th June 1962



(d) 1200 Hours 7th June 1962



(e) 0000 Hours 8th June 1962 (f) 1200 Hours 8th June 1962



(g) 0000 Hours 9th June 1962 (h) 1200 Hours 9th June 1962

Fig. 9 - Potential Refractive Index Cross-Sections

The K cross-sections are constructed from measurements taken at only four points on the abscissa, namely Lerwick, Shanwell, Hemsby and De Bilt. All the information appearing in Fig. 9 between these points is interpolation, arrived at both by reference to the positions of the K values on the four ordinates, as well as the information published in the weather charts. While a large part of the K cross-sections appears to be dependent on interpolation, it must be remembered that it is usual for anticyclonic weather conditions to extend over great distances with little variation, and the cross-sections may therefore be relied on to give a reasonably good picture of the structure of the lower atmosphere at the time for which they are constructed. It may therefore be justifiably concluded from Fig. 9 that when high signals are received, a subsidence boundary layer exists up to heights of 500 metres over the coastal regions. It is assumed that such layers extend over the North Sea at the same heights. The exceptionally high signals received are, on occasions, well above the free-space values, and it is assumed that they occur when ducts are in existence over the North Sea. Subsidence boundary layers also occur at heights in the region of 800 to 1700 metres, and it is probable that these layers are partly responsible for the signals received at the greater distances.

4. CONCLUSIONS

Simultaneous measurements at 774 Mc/s and 560 Mc/s reveal that, in general, the field strengths over distant sea paths are greater for the higher frequency but the difference is not significant, and may be neglected in the planning of a u.h.f. television service.

The field strength/distance curves derived from the simultaneous measurements were made over a relatively short period of time, and therefore no fair comparison may be made with the C.C.I.R. (Geneva 1963) curves; the higher gradient of the 1% curve compared with the C.C.I.R. curve is an indication that different meteorological conditions existed during the two measurement periods.

The field strengths exceeded in each month varied over a greater range at the lower time-percentages than at the higher time-percentages.

The slow-fading type of signal received at Happisburgh occurred for approximately 7% of the total time and the fast-fading type of signal for 93% of the time. The slow-fading type of signal is normally associated with the higher levels of field strength prevalent during anticyclonic weather, whereas the fast-fading type is associated with low-level field strength values received during cyclonic weather.

Signals approaching or exceeding the free-space value are likely to be received when intense high pressure systems are situated in the region of the transmission paths. The exceptionally high signals may persist for prolonged periods of time and during these periods the diurnal variation of signal tends to reach its peak value in the late afternoon and evening.

The potential refractive-index cross-sections indicate that when high signals are received over a transmission path a horizontally stratified subsidence boundary layer exists at heights up to 400 m. The received signals on these occasions invariably approach or are above the free-space value. Boundary layers at heights of 800 metres and 1700 metres, in conjunction with the layers at heights up to 500 metres, are thought to be responsible for the below free-space signals received at the more distant sites.

5. ACKNOWLEDGEMENTS

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